

# **SUPERMOCA: COMMERCIALY-DERIVED STANDARDS FOR SPACE MISSION MONITOR AND CONTROL<sup>†</sup>**

Michael K. Jones  
Senior Member of  
Engineering Staff  
Jet Propulsion Laboratory of  
the California Institute of  
Technology  
Pasadena, CA

Carlos Carrion  
Member of Engineering Staff  
Jet Propulsion Laboratory of  
the California Institute of  
Technology  
Pasadena, CA

Elin L. Klaseen  
Senior Research Engineer  
SRI International  
Menlo Park, CA

## Abstract

This paper describes the Space Project Mission Operations Control Architecture (SuperMOCA). SuperMOCA is a monitor and control architecture that encompasses space mission operations centers, ground terminals, and spacecraft. The paper describes (1) an overview of space mission monitor and control, (2) the architecture, standards, and technologies that comprise SuperMOCA, (3) the relationship of SuperMOCA to current industrial applications in monitor and control of devices, (4) how SuperMOCA addresses current problems in space mission monitor and control, and (5) demonstrations of a subset of SuperMOCA technologies in testbeds. The paper concludes with a discussion of the plan for promoting a commercial market for space mission operations monitor and control products.

and spacecraft. This architecture is intended to promote the growth of a market for space mission operations monitor and control products through a set of open standards. The demand for monitor and control capabilities compliant with these standards will lead to a diverse set of commercial products that can then be integrated to produce monitor and control systems. These commercial products will be available to support the development and operations of spacecraft, ground terminals, and mission operations centers. Standards-based commercial products already exist in markets that are similar to space mission applications (e.g., manufacturing automation and industrial process control applications). Mass marketed commercial products are cheaper to acquire, operate, and maintain and are more interoperable and reliable than the "home-grown" capabilities produced by each individual space mission operations agency and their usual contractor support. This architecture features:

## Introduction

The Space Project Mission Operations Control Architecture (SuperMOCA)<sup>†</sup> is a monitor and control architecture that encompasses space mission operations centers, ground terminals,

- open standard interface specifications
- standard capabilities for describing the characteristics and behaviors of ground

---

\* Copyright ©1998 The American Institute of Aeronautics and Astronautics Inc. The U.S. Government has a royalty-free license to exercise all rights under the copyright claimed herein for Governmental Purposes. All other rights are reserved by the copyright owner.

<sup>†</sup> The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

- and flight devices that are to be monitored and controlled
- a layered design to facilitate insertion of commercially developed products into space mission applications
- capabilities drawn from commercial monitor and control applications.

### Background

Shrinking government budgets and the increased competition of expanding commercial markets for space-based products and services are forcing the space community to reduce space mission costs. The space community is a diverse set of organizations, including:

- government agencies (e.g., NASA, DOD, NOAA),
- commercial operators (e.g., providers of communications and remote sensing satellites),
- academia,
- aerospace industry.

The changes in this community include:

- a shift towards decentralization in mission strategy, with movement away from "a few expensive spacecraft launched relative infrequently" and towards "many affordable spacecraft launched relatively often";
- a need to significantly reduce the costs of operating the increased numbers of small spacecraft without sacrificing either mission flexibility or capability;
- advances in space microelectronics which allow increased automation and autonomy to be packaged into small spacecraft that can be deployed using less expensive launch vehicles; with these advances, the scope and complexity of the remaining human user operations may be significantly reduced. Reduced human operations complexity reduces operations costs and increases reliability.
- the emergence of new commercial space operators (often using constellations of satellites) who, driven by the profit motive, seek low-cost "off the shelf" monitor and control systems that reduce the need for capital and operating investment;

- increasing reliance on cooperation (both national and international) to achieve complex space mission objectives in ways that are affordable to individual organizations, with emphasis on reducing wasteful duplication of effort and improving mission effectiveness by sharing infrastructure and capabilities through the promotion of interoperability between the civil, military, and commercial space sectors.

One way to achieve further cost reductions is to provide solutions that benefit the space community while "opening" the space business to a broader set of private companies. Such solutions should:

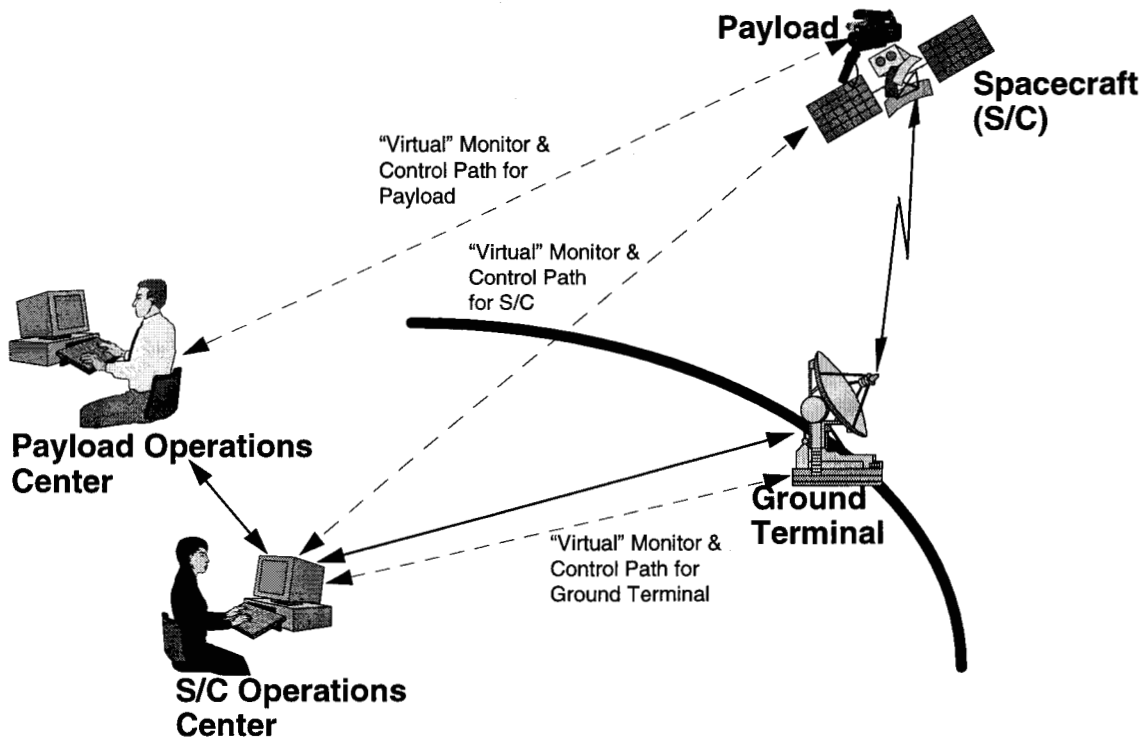
- provide an understanding of the common cost drivers among government and commercial space missions,
- reduce costs for all customers (government and commercial operators) throughout the project life cycle,
- provide business opportunities to a large set of companies,
- promote commercial competition.

### Space Mission Monitor and Control

Using the above concepts as guidelines, SuperMOCA is focusing on reducing the cost and improving the reliability of one area: the monitor and control of space mission systems throughout the project life cycle. Currently space mission monitor and control is significantly re-invented for most missions, resulting in high development and operations costs. The space mission systems which must be operated in a confederated manner in order to execute a space mission include:

- spacecraft and launch vehicles,
- integration and test facilities,
- launch complexes and ground tracking stations,
- operations centers.

An example of a space mission monitor and control application is the operation of an unmanned space mission. Figure # 1 shows a simple schematic of the major flight and ground systems of an unmanned space mission operation. [To keep this schematic



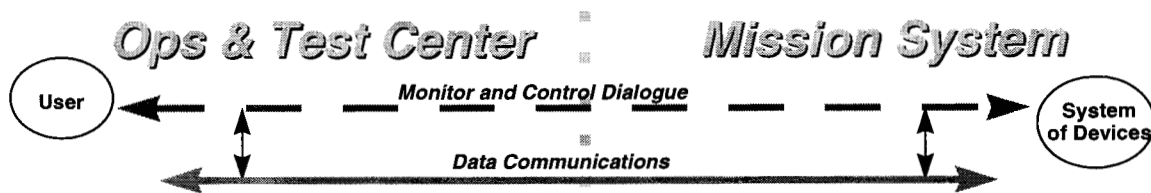
**Figure # 1 - Monitor and control in the operation of an unmanned space mission.**

simple, only two operations centers (one for the spacecraft and one for the science payload carried by the spacecraft), one ground terminal, and one spacecraft/payload are shown, however a given space mission may be supported by a network of multiple operations centers, ground terminals, spacecraft and payloads. Also launch vehicles and launch pad facilities are not shown.]

In this simple model, the monitor and control dialogues between the ops centers and ground terminal, spacecraft, and payload are carried out over "virtual paths" from the payload and S/C operations centers. The communications links to support these virtual paths are between the operations centers and the

ground terminal, between the ground terminal and the spacecraft, and between the spacecraft and the payload. Some level of autonomy resides in the ground terminal, the spacecraft and the payload, allowing local monitor and control even though the ground terminal, the spacecraft, and the payload are unmanned.

SuperMOCA focuses on the monitor and control dialogues between the user in the ops or test centers and the systems of devices that are being monitored and controlled. (See Figure # 2.) The underlying communications protocols and capabilities are not the focus of SuperMOCA, but are the focus of many efforts

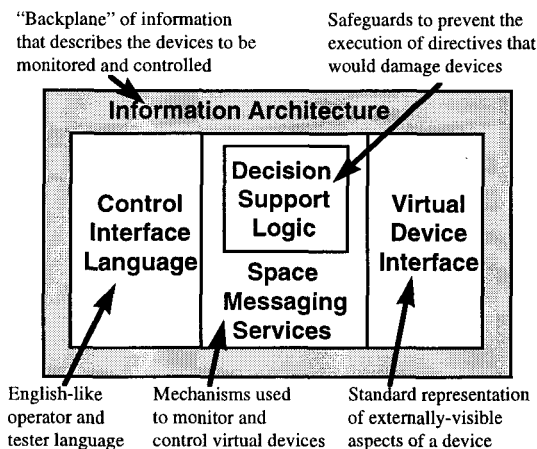


**Figure # 2 - SuperMOCA focuses on the monitor and control dialogue, not the underlying communications capabilities.**

within government to improve the space communication infrastructure.

### SuperMOCA Architecture and Standards

SuperMOCA includes both the architecture and the specification of open standards which enable the architecture to be applied across multiple space mission systems. There are 5 elements of SuperMOCA shown in Figure # 3 and explained below. Note that this figure shows the relationships between the elements, but does not allocate the elements to any flight or ground system.



**Figure # 3 - Five elements of SuperMOCA**

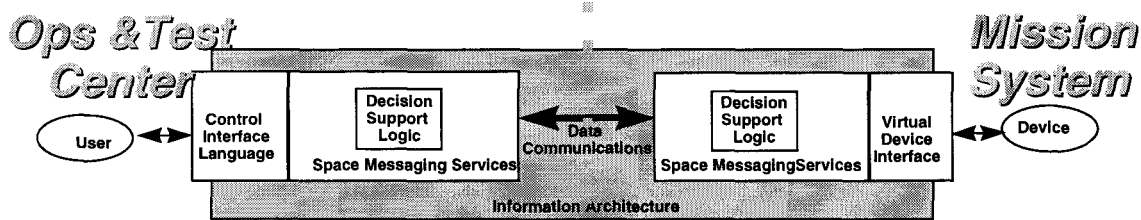
- **Control Interface Language** - At the user interface, this is a text-based, test and mission operator-oriented language allowing the mission operator to monitor and control activities of remote space mission resources.
- **Decision Support Logic** - These are the capabilities that preserve mission resource health by preventing any control

commands from being executed that would damage the resource.

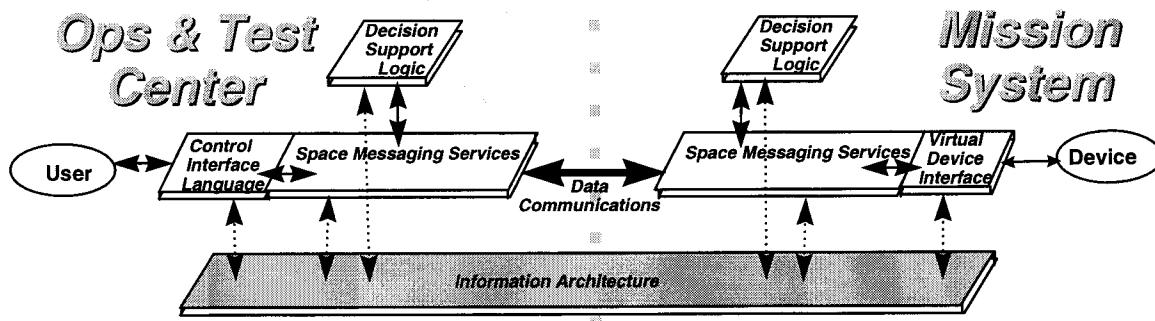
- **Space Messaging Service** - This provides a standard set of messaging services that are the mechanisms used to monitor and control a set of virtual devices.
- **Virtual Device Interface** - At the device interface, this is a representation (constructed with standard components) of the externally-visible aspects of the device that can be monitored and controlled.
- **Information Architecture** - This is the standardized structure into which the monitorable and controllable characteristics of devices can be captured and used to configure the generic capabilities of SuperMOCA for the specific mission.

Figure # 4 shows a representative distribution of the 5 elements of SuperMOCA across ground and flight systems. It also shows a data communications capability to support the transport of monitor and control data between ground and flight systems. The user on the ground and the controlled device in flight are conducting a monitor and control dialogue.

The user issues directives and receives monitor information via the control interface language. The control interface language includes an interpreter that translates between the user control language and the standard directive and status messages exchanged through the message services. Also shown are the decision support applications that assist the user in the monitor and control process. These applications determine whether directives are safe and effective and prevent the execution of any that are not safe and



**Figure # 4 - SuperMOCA elements connecting user and controlled device distributed across ground and flight.**



**Figure # 5 - Layered view of elements of SuperMOCA.**

effective. The space messaging services are the mechanisms that provide a consistent and universal way to communicate monitor and control messages between ground and flight.

Monitor and control information is placed in and extracted from messages at both the user and mission system conducting the monitor and control dialogue. The messaging system specified by SuperMOCA is currently limited to devices in mission systems. These devices are monitored and controlled through the virtual device interface. All the other elements of SuperMOCA depend on the "background" of device descriptions contained in the information architecture (shown in grey in the figure) in order to "know" the possible behaviors of the devices and their configuration into a system.

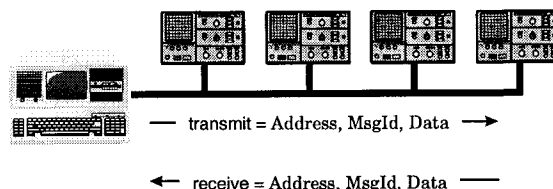
Figure # 5 shows these same elements, but illustrates a layered, hierarchical view of the elements and interfaces in the SuperMOCA architecture. Layering allows increased visibility of commonality among the mission systems and enables the use of standards based on common interfaces between the layers. One key feature of the layered architecture is that each layer provides services to the layers immediately above and below it. Each layer provides a higher level of services than the layer below resulting in the level of abstraction increasing in each higher layer.

#### Commercial Device Monitor and Control Technologies

The SuperMOCA standards work currently focuses on monitor and control of the set of

devices distributed across space and ground systems that must be orchestrated in order make the overall mission work. The remainder of the technology discussion in this paper will focus on messaging systems (that provide messaging services) and virtual devices. As stated earlier, for these two elements of SuperMOCA, there are commercial products based on open standards that can be the basis for space mission monitor and control open standards and products.

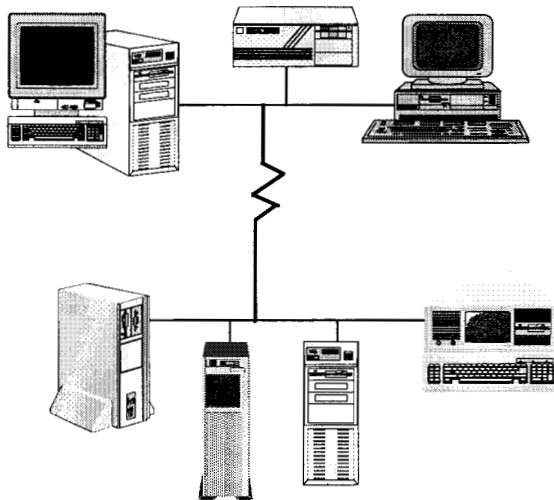
There are many commercially available messaging systems. They have been developed for a variety of applications and in a variety of communications and computing environments. The simplest messaging systems (shown in Figure # 6) provide only the protocols for transmit and receive services using a message structure with a message identifier. The protocols must be implemented by each of the devices and the monitoring and controlling applications on the network. They provide the addressing necessary to support communications with multiple devices over only a single network.



**Figure # 6 - Simple, single-network messaging system environment**

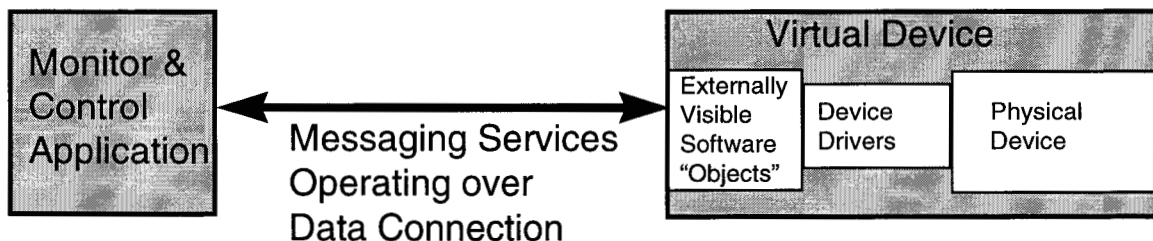
More sophisticated messaging systems might be applied in an environment such as that shown in Figure # 7. These type of messaging systems provide a large set of messaging

services. This set of messaging services includes more than just transmit and receive capabilities. These messaging systems define specific protocols for different types of data types and for various automatic message response requirements (such as receipt confirmation). These type of messaging systems also define a set of allowed data structures within the messages. These systems generally provide for addressing that supports exchange of messages over multiple networks. These messaging systems include the software capabilities to be installed at the devices and at the monitor and control application nodes to implement the full set of messaging services.



**Figure # 7 - Sophisticated, multiple-network messaging system environment**

Some of the more sophisticated messaging systems are designed to support interactions between monitor and control applications and virtual devices. See Figure # 8. In these systems, messaging services are defined so as to facilitate the monitor, control, configuration, and trouble-shooting of these virtual devices.



**Figure # 8 - Monitor and control of a virtual device via messaging services.**

In general, a virtual device is a representation of the externally-visible attributes of a given device that can be monitored or controlled. As implemented, a virtual device is a collection of one or more standard software components associated with a given device that allows monitor and control applications that are external to that device access the device's functionality. When that device is attached to a network, the virtual device is the network-visible representation of the attributes of the device.

The SuperMOCA task has examined two such sophisticated messaging systems and virtual device concepts. The specifications for these systems are open standards in industry. The specification for manufacturing automation (used, for example in automotive assembly lines) is called the Manufacturing Messaging Specification (MMS). The one for the process control industry (used, for example, in chemical processing plants) is called the Fieldbus Messaging System (FMS). These two open standards and the possibility of their use as the basis for the Space Messaging Service open standard is discussed later in this paper. These two standards have associated commercial products that fit readily into the testbed environments SuperMOCA has been using to investigate messaging systems for space mission applications. These testbed environments are discussed later in this paper.

#### Addressing Problems of Monitor and Control

The main cost reduction feature in SuperMOCA is the use of commercial products that are cheaper than "in-house" products to acquire, operate, and maintain and, as well, are more reliable. They are cheaper because

product development and improvement costs are amortized over a large customer base. They are more reliable because the large customer base detects problems and feeds back information to the vendors to improve product reliability. In general, costs throughout the mission life cycle can be reduced by the adoption of SuperMOCA open standards.

SuperMOCA addresses the following causes of the current expense of space mission system development.

- Monitor and control applications for space mission systems are designed anew for the particular system or are inherited from other systems and extensively modified.
- Devices inherited from other space mission systems must be extensively reworked to make them compatible with current space mission system interfaces and monitor and control methods.

With the SuperMOCA architecture and standards in place, developers will reduce cost by designing to only one monitor and control architecture with one set of standard interfaces. Additional cost reductions in the development phase will occur due to the following.

- Use of the “virtual device” concept for space mission systems will provide standardized input/output interfaces and monitor and control mechanisms that insulate the system designers from vendor-specific design peculiarities that would otherwise affect the monitor and control system design. Each device can still be unique, but its behavior is monitored and controlled via standard “building block” software components.
- Use of the Space Messaging Services standards will provide the designer with an already system-engineered solution for monitor and control functionality needed for any space mission system.

SuperMOCA addresses the following causes of the current expense of space mission system integration and test (I&T).

- Device interfaces frequently fail upon initial integration because they are unique and, therefore, untried.
- Test conductors need extensive training on the specifics of mission system devices in order to conduct system tests. If this level of training is not feasible, then device design experts are frequently required to support integration and test.
- Inconsistent methods for monitoring and controlling systems force complexity into test conductors jobs and/or into test monitor and control systems.

With the SuperMOCA architecture and standards in place, more reliable devices and test monitor and control applications (incorporating increased automation and autonomy) will shorten test schedules and reduce costs. Additional cost reductions in I&T phase will occur due to the following.

- Use of the “virtual device” concept will hide vendor-specific design peculiarities from the user to make devices appear similar in terms of monitor and control.
- Use of the Space Messaging Services standards will give the test conductor a standard set of monitor and control services that are built into the virtual devices and any test monitor and control applications.
- Expanding the use of the virtual device concept to include self-identifying devices for integration and test will enable each device to talk to the system as soon as it is connected. Each device will identify itself and its monitorable and controllable features and the Space Messaging Services it understands. The descriptive data from the device will be structured according to the Information Architecture standard. The test monitor and control applications can be automatically configured upon connection to manipulate the self-identified device.

SuperMOCA addresses the following causes of the current expense of space mission system operations and maintenance (O&M).

- Operators need extensive training on the specifics of mission system devices in order to operate and maintain mission

systems. If this level of training is not feasible, then device design experts are frequently required to support O&M.

- Inconsistent methods for monitoring and controlling systems force complexity into operations jobs and/or into monitor and control applications.

Having the SuperMOCA architecture and standards in place will provide consistent monitor and control interfaces, methods, and applications (incorporating increased automation and autonomy) between system I&T and mission operations. This will reduce operator training and dependence on the use of experts in O&M. This architecture and standards will also facilitate the migration of the automation and autonomy applications from ground implementations to on-board implementations. Additional cost reductions in O&M will occur due to the following.

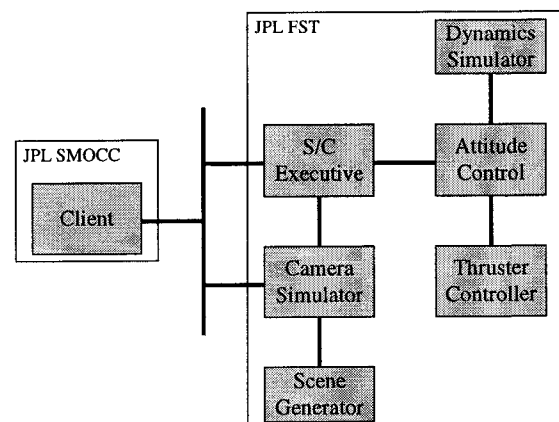
- Use of the “virtual device” concept will hide vendor-specific design peculiarities from the user to make devices appear similar in terms of monitor and control.
- Use of the Space Messaging Services standards will give the operator a standard set of monitor and control services that are built into the virtual devices and any monitor and control applications.

#### Demonstrating Commercial Monitor and Control Technology in Space Mission Applications

The first space mission system demonstration of a commercial monitor and control products based on an open standard protocol was implemented in 1992. Some subsystems of a research and development antenna in the Deep Space Network were configured to be monitored and controlled via commercial products based on the Manufacturing Messaging Specification (MMS).<sup>2</sup> This demonstration showed the ease of installation and immediate applicability of a commercial messaging system to control of a space mission ground terminal.<sup>3</sup>

SuperMOCA is currently testing and demonstrating open standard protocols from commercial applications in simulated space mission environments.

One demonstration uses commercial products based on MMS installed in simulated spacecraft facilities at JPL.<sup>4</sup> This demonstration conducts a typical observation scenario of an unmanned spacecraft. The scenario is the monitor and control of a mosaic (a set of images of size  $m$  rows by  $n$  columns) centered on a target. As shown in Figure # 9, the Flight System Testbed (FST) at JPL provides the simulated spacecraft. Two spacecraft subsystems of the FST are used: the Attitude and Articulation Control Subsystem (AACs) and the Camera Simulation. The Simulated Mission Operations Control Center (SMOCC) is used as the development and runtime environment.



**Figure # 9 - Spacecraft demonstration testbed.**

The functional blocks in the scenario are: a client that is used by the user to run the scenario, a spacecraft controller that controls the execution of the mosaic, a camera that takes each image in the mosaic, and an attitude control subsystem that performs the spacecraft turns to point the camera.

To start the scenario, the user connects to the spacecraft controller and camera simulator. The user defines the mosaic by specifying the number of rows, number of columns, amount of overlap between images in each direction, and the target quaternion. This is done by writing to variables in the spacecraft executive. The user then sets the exposure time, and selects the imaging filters for the images by writing to variables in the camera simulator. The user can also direct the camera simulator to compress the “images”. The user also initializes the simulated spacecraft via a setup



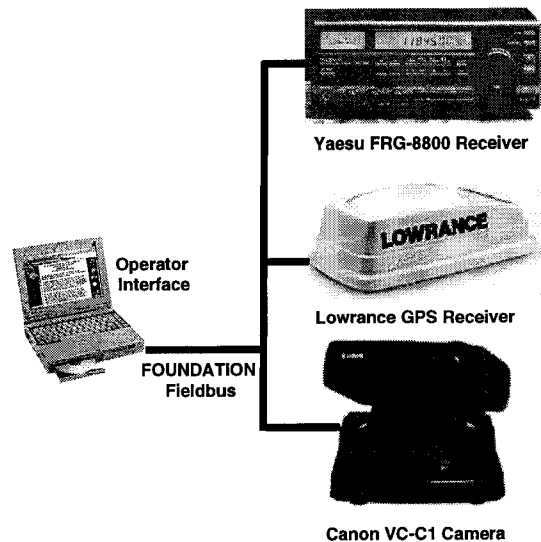
script which starts the dynamics simulation (world model), the spacecraft radio, the spacecraft's computer flight software (including the attitude control software), and the camera simulator support equipment (scene generator).

The user then directs the spacecraft executive to start the mosaic execution. The executive then connects to the attitude control subsystem and to the camera simulator. The executive builds the mosaic command from the variables that were written by the user and sends the mosaic command to attitude control. The attitude control subsystem takes care of the interface to the simulated spacecraft in the FST and the spacecraft begins the turns. From this point on the execution is controlled by the spacecraft executive which instructs the camera simulator to take an image after each turn completion. After the execution is complete, the executive informs the client that the mosaic has been completed.

At this point, the user can do several things: for example, download the "images" from the camera simulator, delete the "images" from the camera simulator file store, instruct the camera simulator to execute one of two stored maintenance scripts which can be overwritten by the user via the client. The user then closes the connections to the executive and camera simulator. The spacecraft executive then closes its connections to the attitude control subsystem and camera simulator.

A second simulated mission environment is the SuperMOCA Road Show Demonstration shown in Figure # 10. The demonstration uses the Fieldbus Messaging System (FMS)<sup>5</sup> to link a camera, a radio receiver and a Global Positioning System (GPS) receiver to controlling applications. The demonstration system is analogous to an unmanned space mission operation. The camera represents a part of the mission payload and the pointing system of the spacecraft. The GPS receiver and the radio receiver represent an additional parts of the mission payload. Each of the devices have a FMS-compatible processor that is used to implement the virtual device software. These processors and the FOUNDATION Fieldbus network represent the on-board computing capability of the

spacecraft and the payload. The PC computer with its operator interface and host application software represents the operations center. This is used by the operators to monitor and control the actions of the payload.



**Figure # 10 - Road Show demonstration.**

#### Creating a Commercial Market Solution

Initially, SuperMOCA will provide the common understanding and open standards to facilitate the migration from in-house products to adopted or adapted commercial products. As more experience is gained in the use of these standards more costs will be saved. In the long run, wide-spread use of these standards will promote a commercial market for space mission monitor and control products. This commercial market will be promoted through the use of:

- operations concepts developed in concert with a space community working group (Spacecraft Control Working Group) that provide a common understanding of the cost drivers,
- a corresponding architecture that:
  - is developed with the same working group,
  - provides a framework for the solution,
  - delineates the common infrastructure and the mission-specific variations built on it,
  - defines a standard interface to the common infrastructure so that commercial companies can avoid

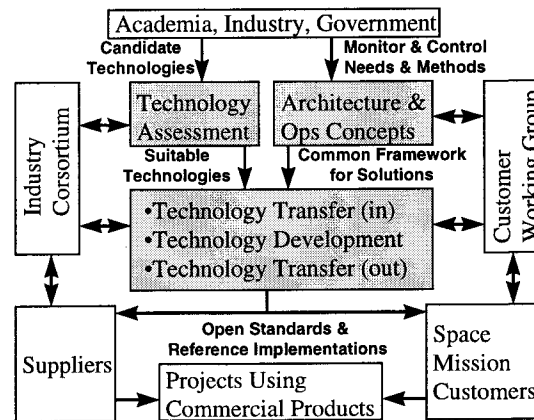
- investing development resources in mission-specific interfaces and instead focus on product performance improvements,
- the Space Messaging System, an open standard for the space environment that is derived from current commercial open standards,
- a standard and method for carrying system descriptive information seamlessly throughout the project life cycle and from mission to mission,
- cooperation of a non-profit industry consortium that shows an interest in space applications (the Fieldbus Foundation in the process control industry).

SuperMOCA is working with the Fieldbus Foundation and some of their member companies to:

- Provide technical review of their on-going work to expand FMS to work in ethernet networked environments
- Develop a space monitor and control industry consortium based on the Fieldbus Foundation experience as a process control industry consortium
- Develop a design for remote access to monitor and control systems on earth via earth-orbiting satellite communications links

### Conclusion

SuperMOCA is drawing from academia, space industry, earth-bound industries, and government agencies to formulate a solution following the path shown in Figure # 11. The suitable technologies are being adapted for space mission applications in cooperation with both industry and customers (i.e., government, academic, and commercial operators of space missions). Ultimately, the effort will produce a set of standards and reference implementations of those standards. The customers will require suppliers to provide products that meet these standards and the industry will develop commercial products to meet these requirements.



**Figure 11 - Path to the commercial product solution.**

<sup>1</sup> Much more information about SuperMOCA, including the below listed papers, can be found at the SuperMOCA Web Site at

"<http://supermoca.jpl.nasa.gov/supermoca>".

<sup>2</sup> A description of the commercial protocols considered and the rationale for selection of MMS for this demonstration is in "Open Solutions to Distributed Control in Ground Tracking Stations", W. Randy Heuser.

<sup>3</sup> A discussion of the application of MMS technology to space missions is in "Industrial Protocols for Spacecraft Command and Control", W. Randy Heuser

<sup>4</sup> A detailed description of this demonstration is in "An Implementation of a Commercial Messaging System Standard for a Space Mission Application", Carlos Carrion

<sup>5</sup> A discussion of the application of FMS technology to space missions is in "Cost Reduction Through Application of Fieldbus Technology to Space Mission Operation and Control", Elin Klaseen, Michael Jones, Lee Neitzel.